Radiative Transfer Calculations for Thermal Radiation from GRB Jet

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- Method
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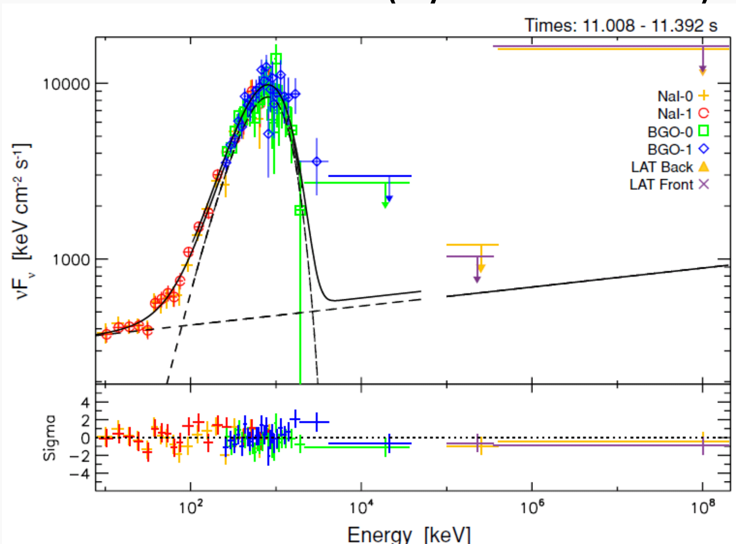
Introduction

Models for the prompt emission

- Internal shock model
  - A standard scenario for a long time.
  - Some problems (e.g., low energy spectral index)
- Photospheric (thermal emission) model
  - Thermal emission from relativistic jets
  - Some GRBs exhibit blackbody like feature (e.g., GRB090902B).

(Ryde et al 2010)



Photospheric emission?

- The dominant opacity source in the jet is electron scattering.
- The photosphere is a surface of τ_{scat}=1.
- The actual position of the photon production is much inner region. (e.g., Beloborodov 13)

→ Necessity of the radiative transfer

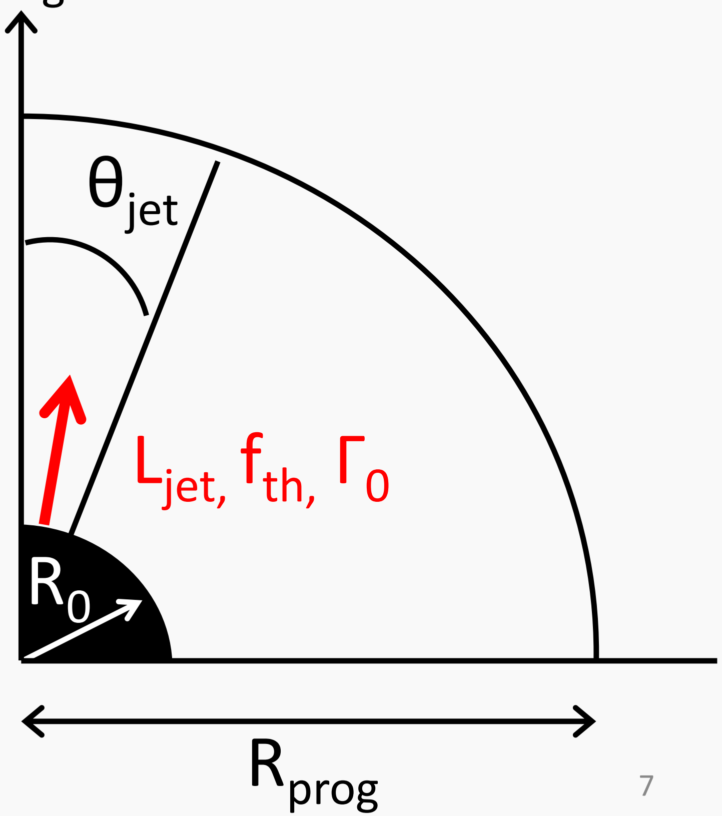
Method

Hydrodynamic simulation

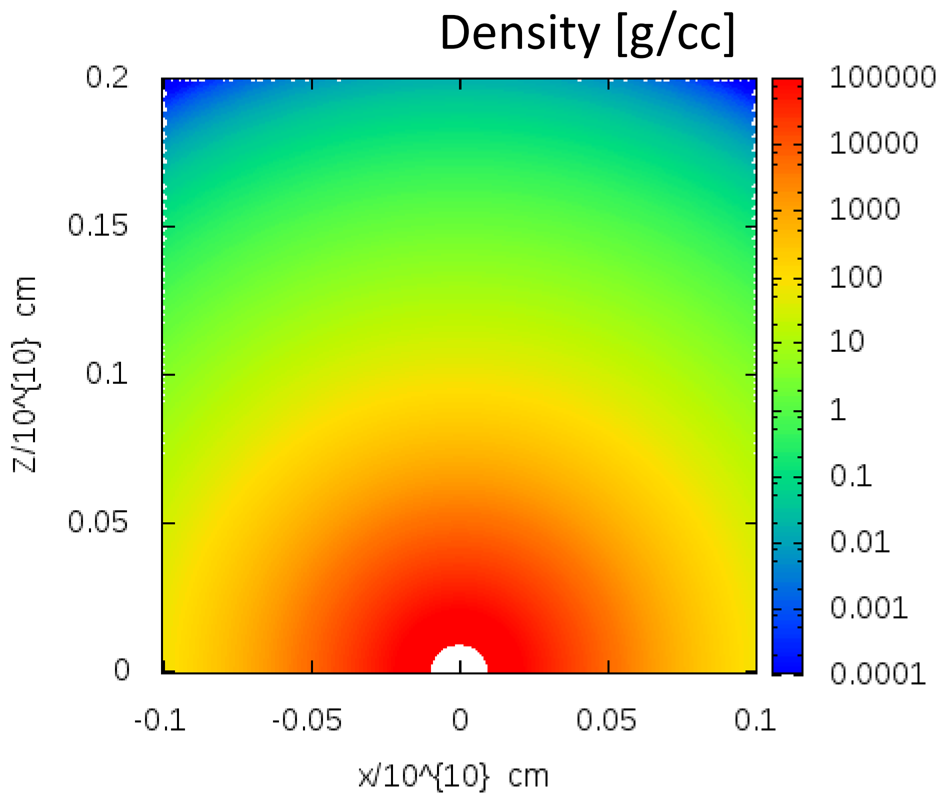
✓ 2D relativistic hydrodynamics (Tominaga 2009)

✓ Setup

- Progenitor: 15M_{sun} WR star (R_{prog} ~ 2.3×10^{10}cm)
- Γ_0=5
- Θ_{jet}=10°
- $L_{jet}=5.3 \times 10^{50}$ erg s^{-1}
- f_{th}=0.9925 ($e_{int}/\rho c^2$=80)
- (log r, θ) = (600, 150) grids
  from $R_0=10^9$cm



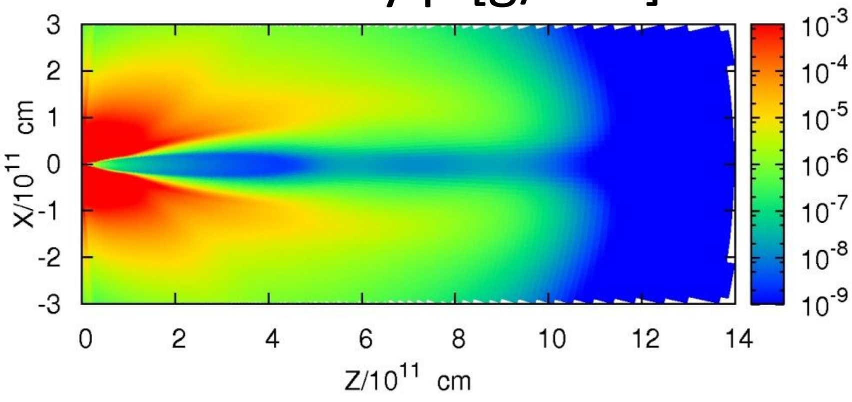
Hydrodynamic simulation



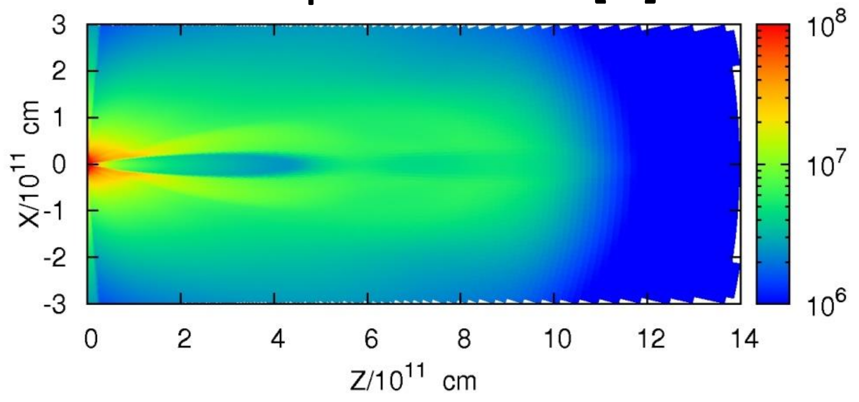
Hydrodynamic simulation

- We use a snapshot at 40s for the structures of the jet and cocoon.

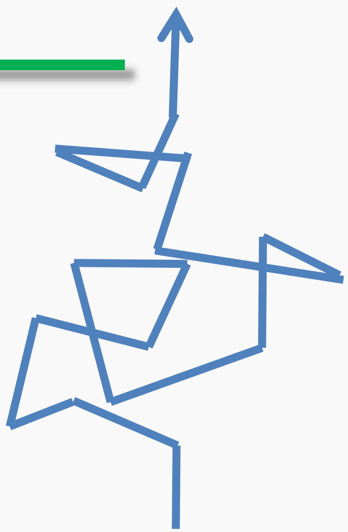
Density ρ [g/cm³]



Temperature T [K]



The effective optical depth



- The effective optical depth τ_*

  For static medium (e.g., Rybicki & Lightman 1979)

  $$\tau_*^{\mathrm{NR}} \sim \sqrt{\tau_{\mathrm{a}}(\tau_{\mathrm{a}}+\tau_{\mathrm{s}})}$$

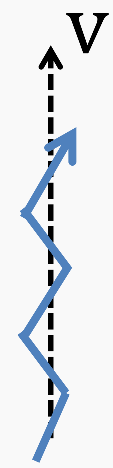
  For relativistic medium (Shibata, Tominaga & Tanaka 2014)

  $$\tau_*^{\mathrm{R}} = \left\{\frac{\Gamma^2}{3}(\beta^2+3)+(\Gamma\beta)^2\frac{\tau_{\mathrm{s}}}{\tau_{\mathrm{a}}}\right\}^{-1/2}\frac{\sqrt{\tau_{\mathrm{a}}(\tau_{\mathrm{a}}+\tau_{\mathrm{s}})}}{\Gamma(1-\beta\cos\theta_{\mathrm{v}})}$$

  $$\tau_{\mathrm{a}} = \Gamma(1-\beta\cos\theta_{\mathrm{v}})\alpha' L \;,\quad \tau_{\mathrm{s}} = \Gamma(1-\beta\cos\theta_{\mathrm{v}})\sigma' L$$

  In the non-relativistic limit, $\tau_*^{\mathrm{R}} \rightarrow \tau_*^{\mathrm{NR}}$

  In the relativistic limit, $\tau_*^{\mathrm{R}} \rightarrow 2\,\tau_{\mathrm{a}}$ for Θ=0



The photon production sites

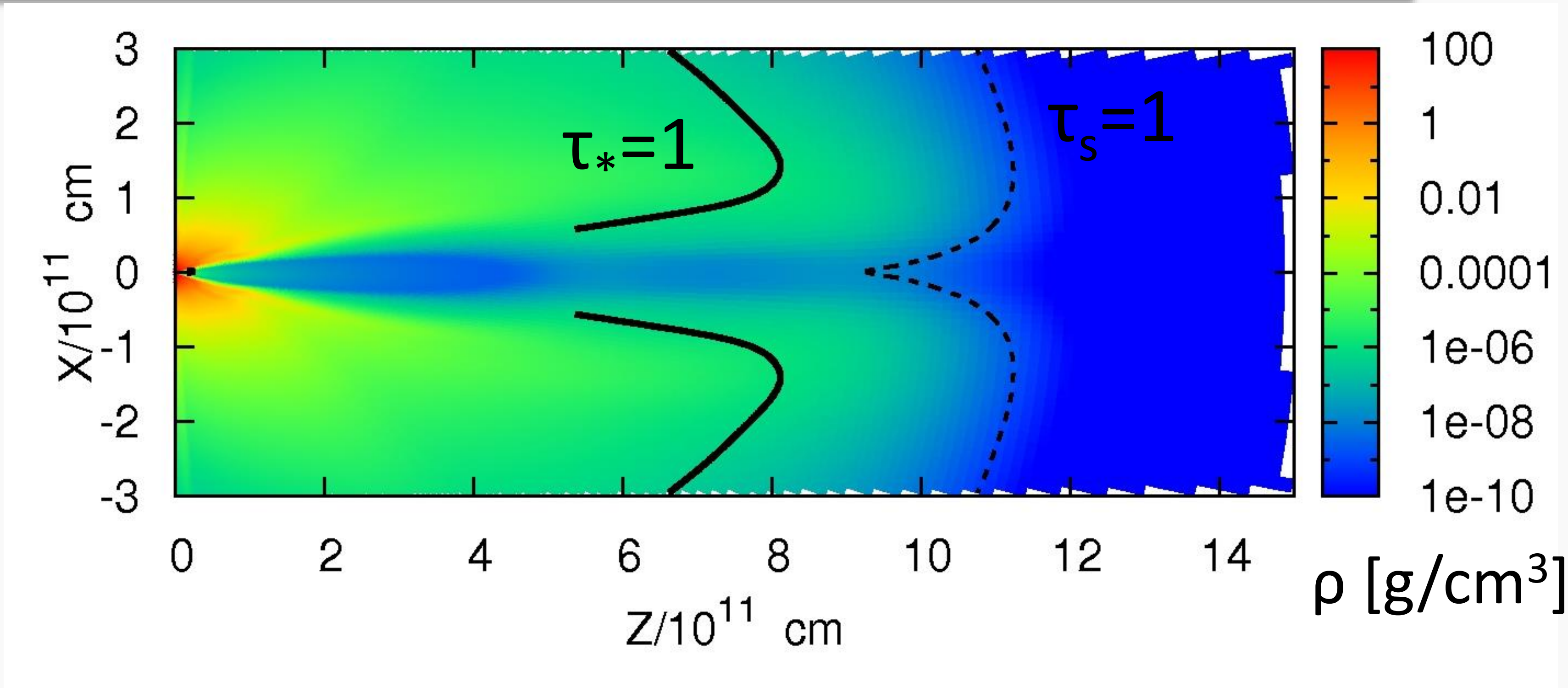
- τ_* to a radius R_*

$$\tau_* = \int_{R_*}^{\infty} \left\{ \frac{\Gamma^2}{3}(\beta^2+3) + (\Gamma\beta)^2 \frac{\sigma'}{\alpha'} \right\}^{-1/2} \sqrt{\alpha'(\alpha'+\sigma')}dr$$

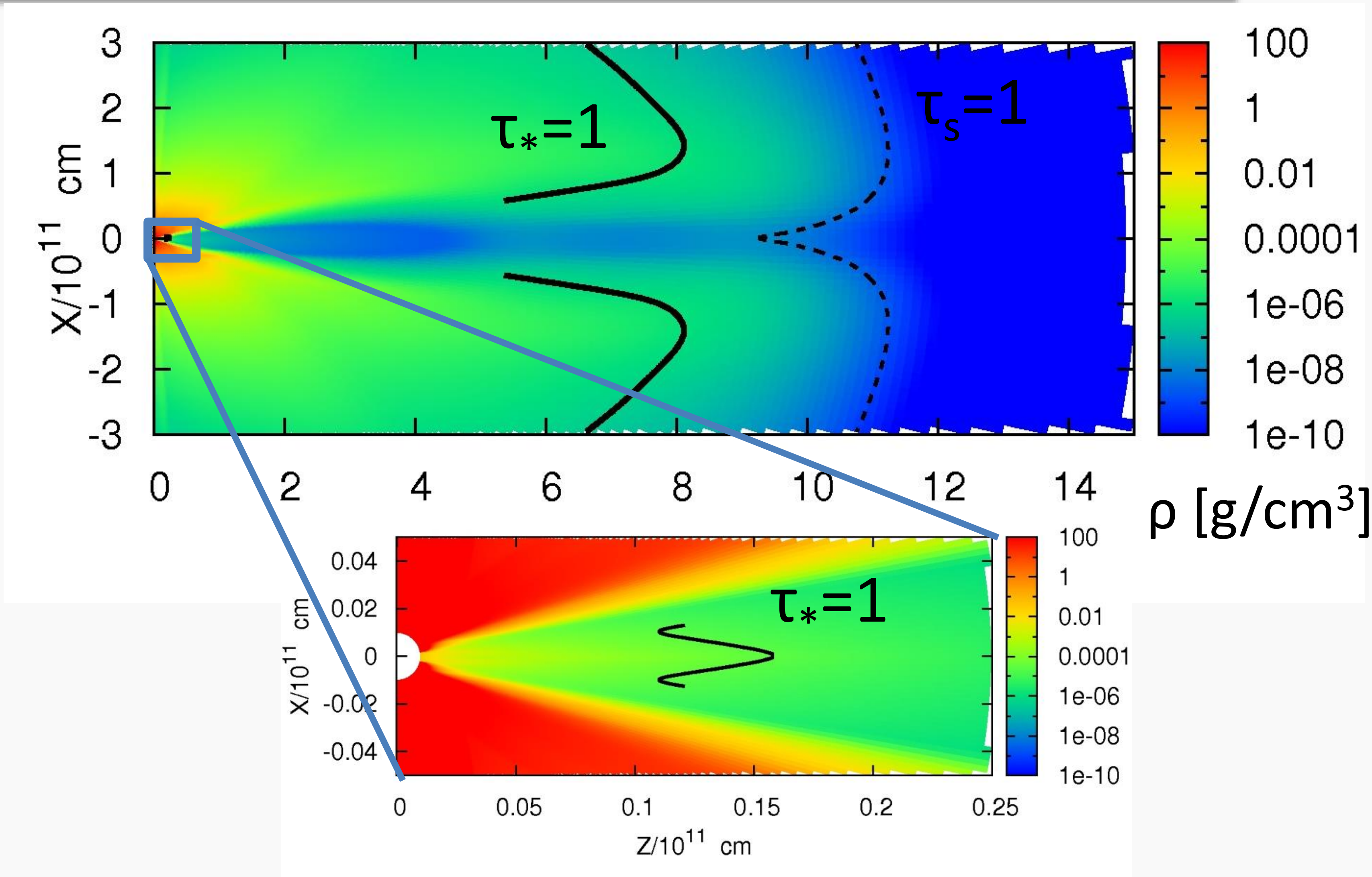
- σ' : electron scattering
- α' includes
  - Free-free absorption (e + p + γ → e + p)
  - Double Compton absorption (γ + γ + e → γ + e)

We find the R_* which satisfies $\tau_* = 1$

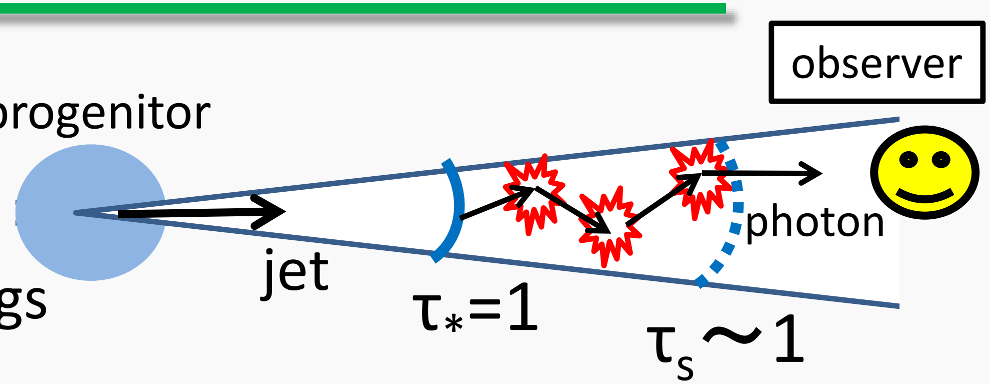
The photon production sites



The photon production sites

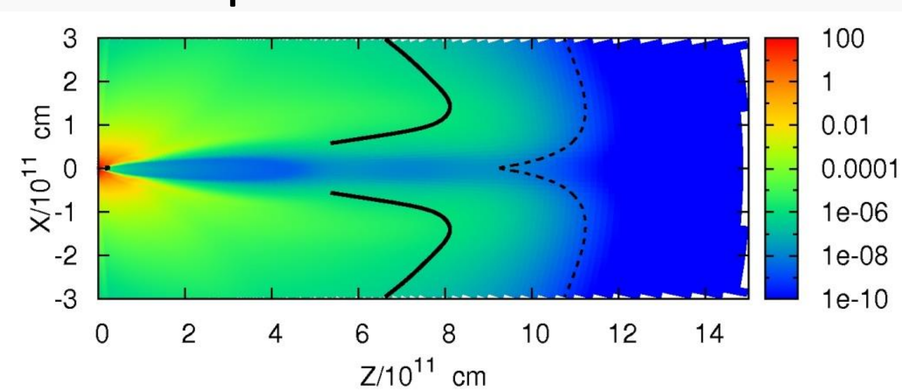


Radiative transfer



- ✓ Numerical code
  - Monte Carlo method
  - Calculate Compton scatterings
  - Photons are injected at $\tau_*=1$
- ✓ Photon injection
  - Spatial distribution: $n_\gamma \propto T^3$
  - Planck distribution with local plasma temperatures
  - Isotropic in the comoving frame

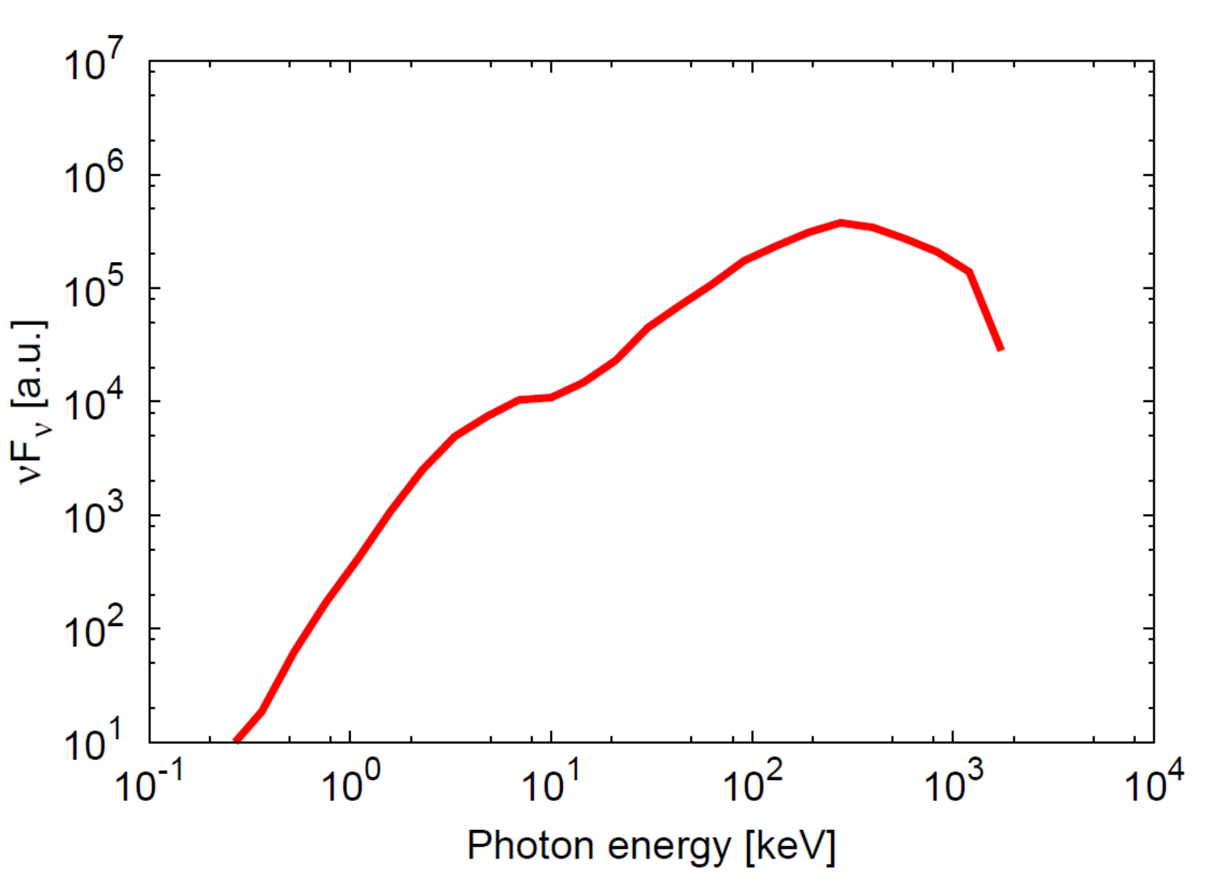
We use a snapshot at t=40s for the jet and cocoon structure.



Results

Observed spectrum

- E_{peak} ~ 300keV
- NOT a blackbody
  - wider than B.B.
- A bump like feature at low energies



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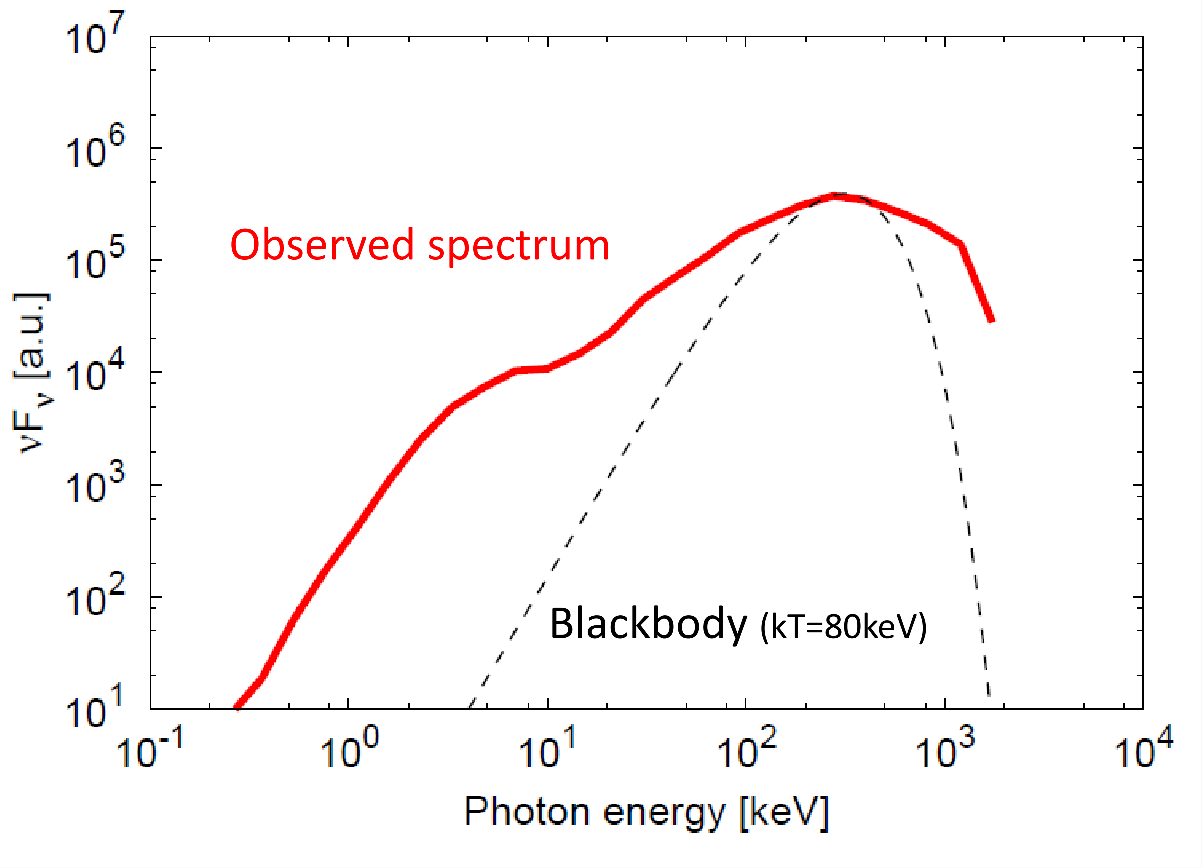
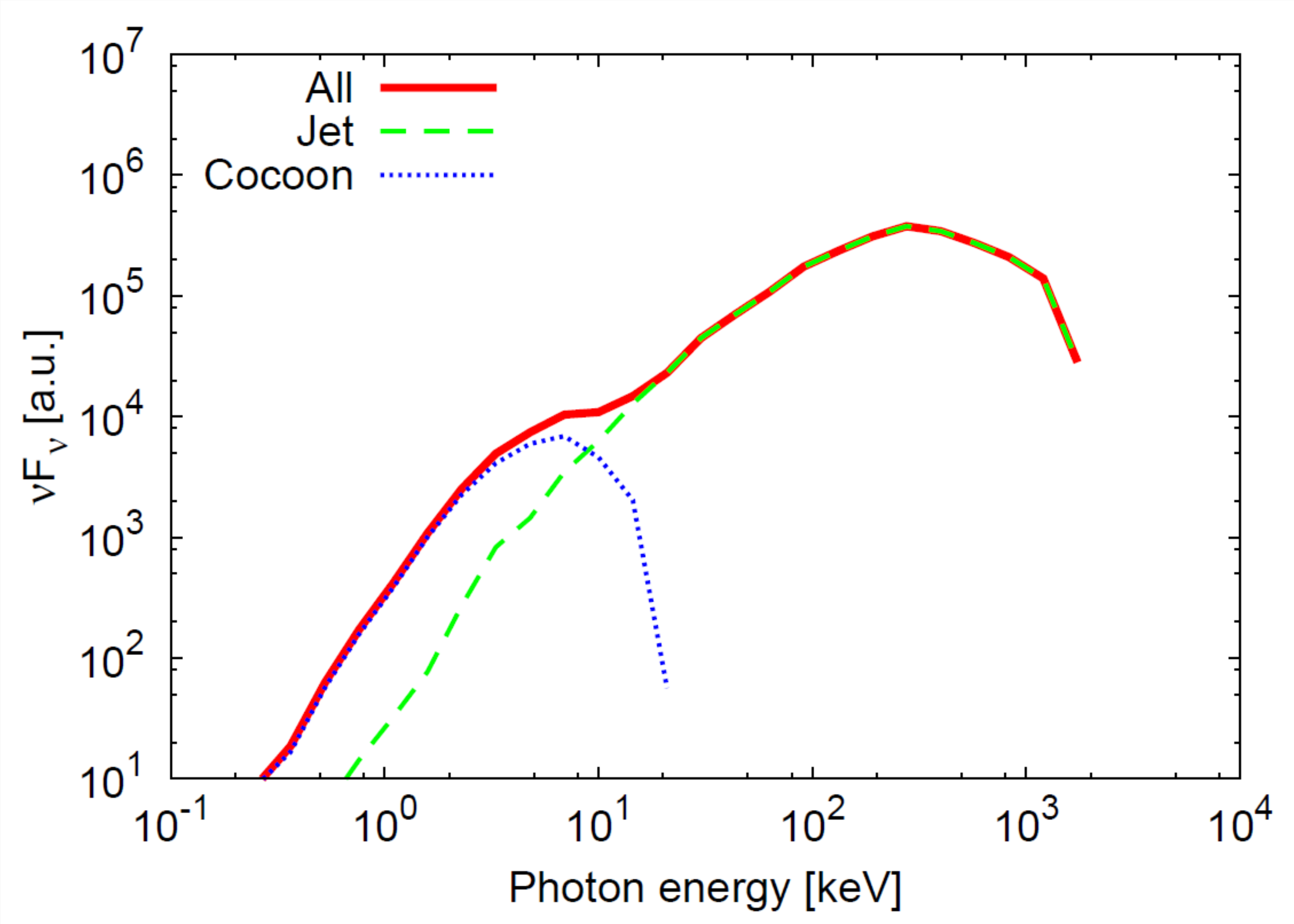


Origin of the bump?



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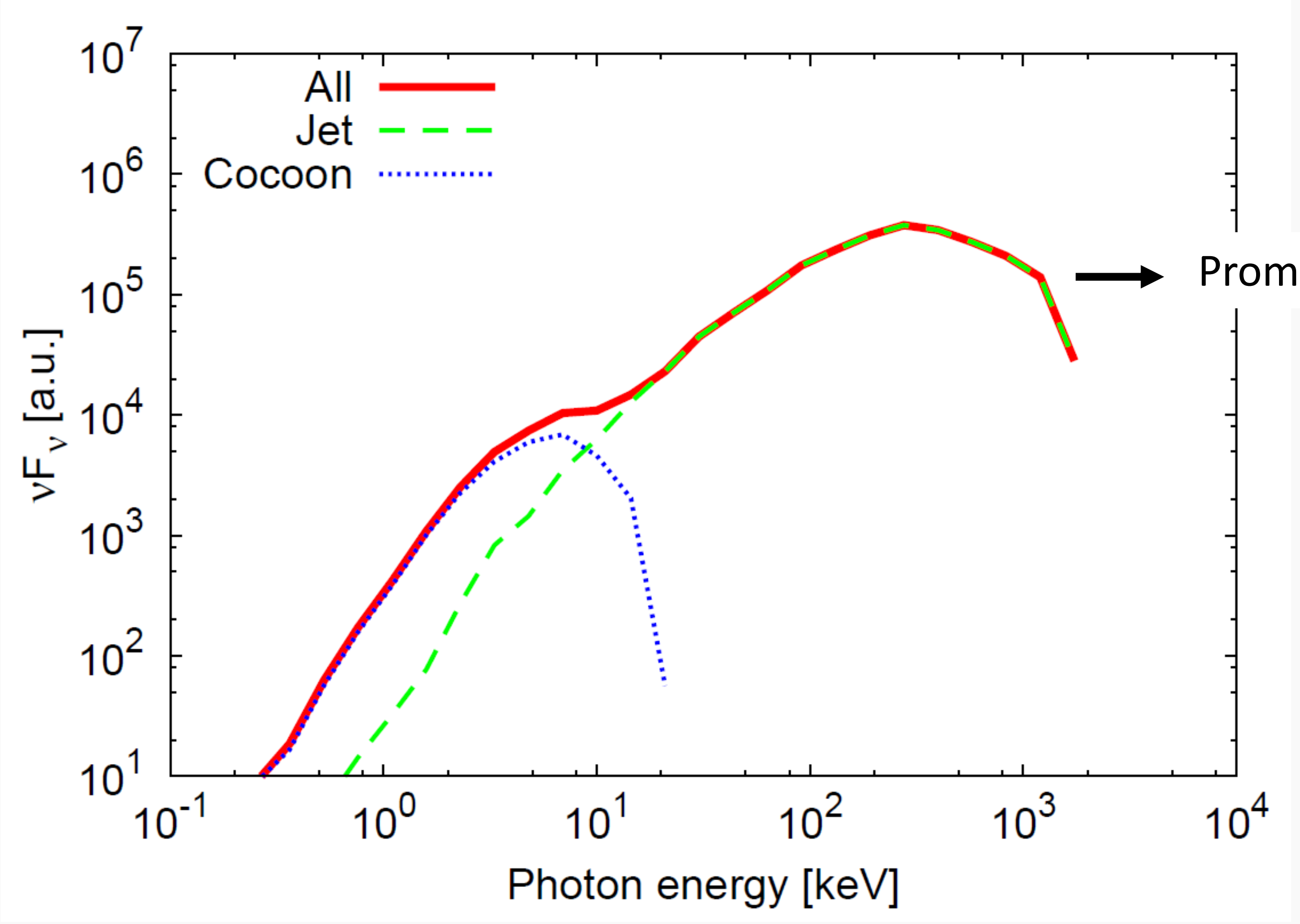
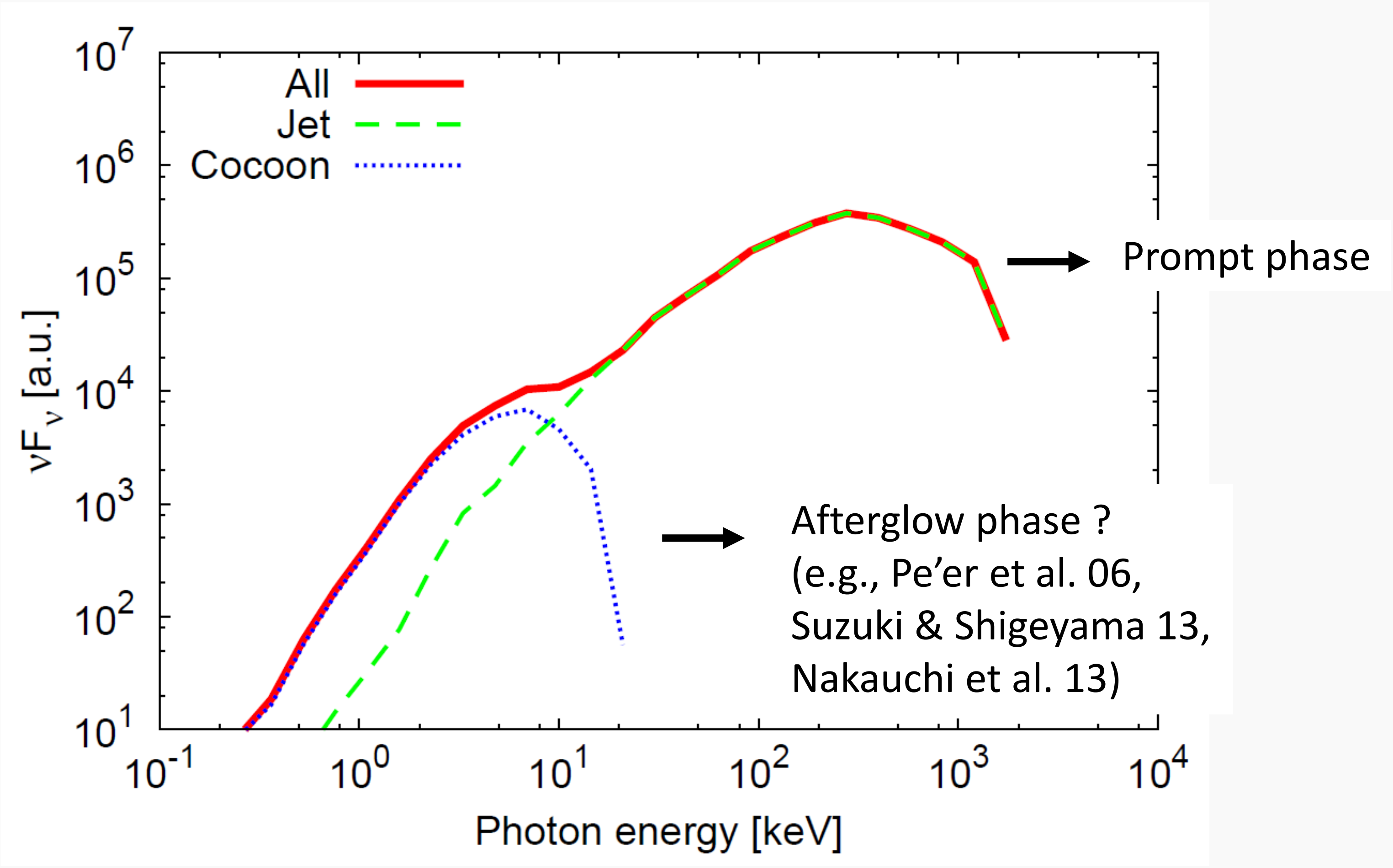
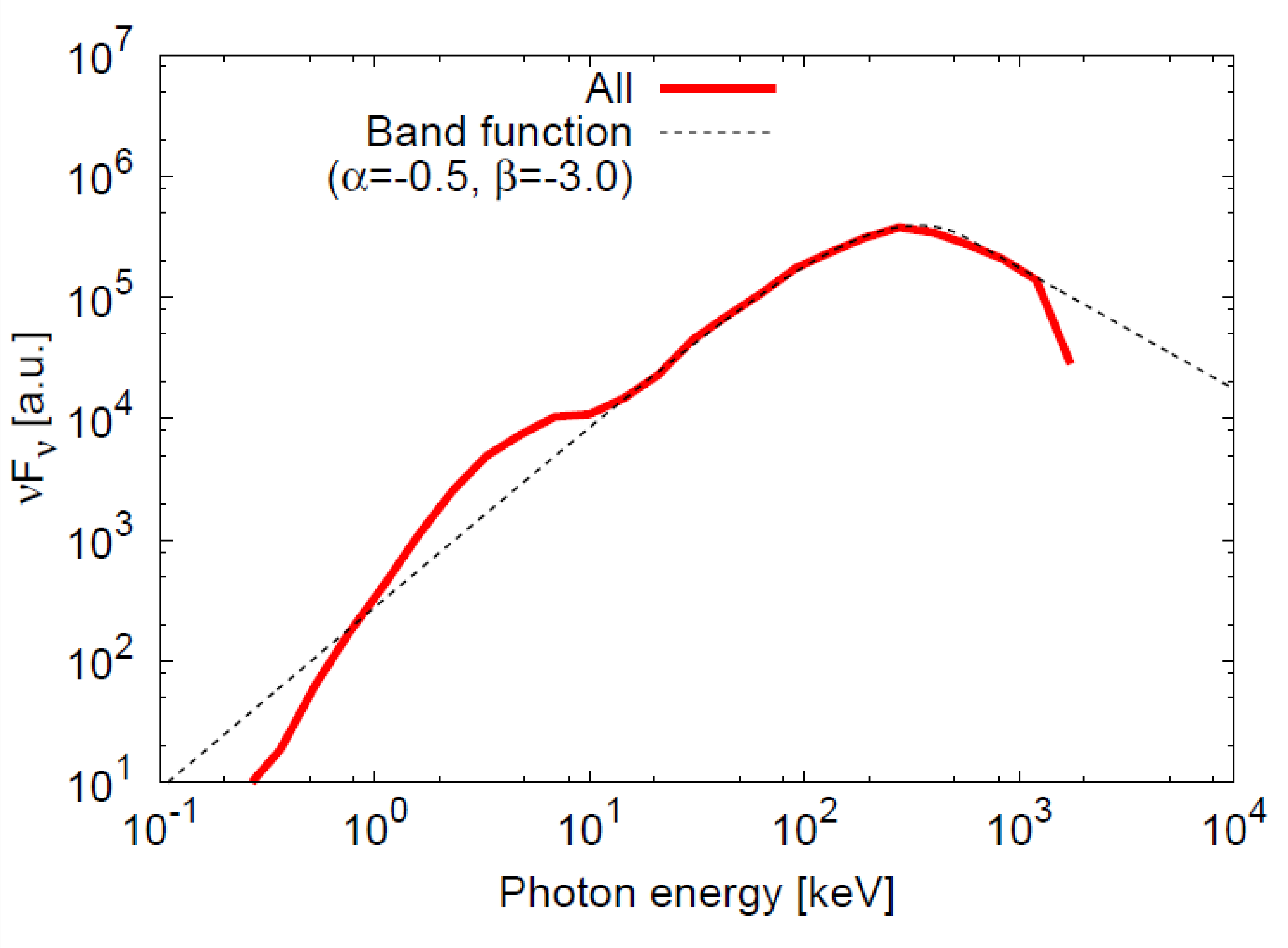


Prompt phase

Origin of the bump?



Comparison with the observations



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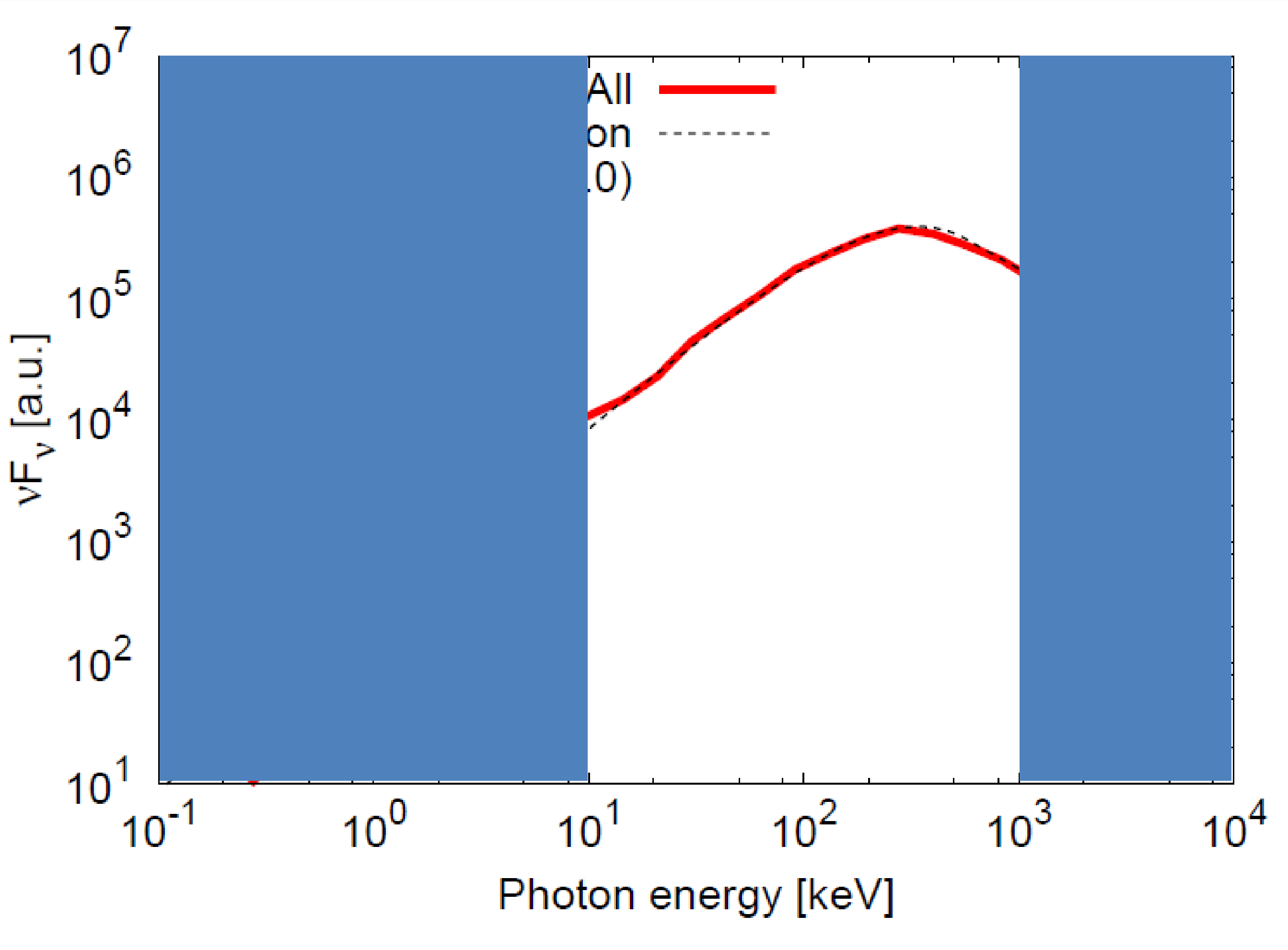
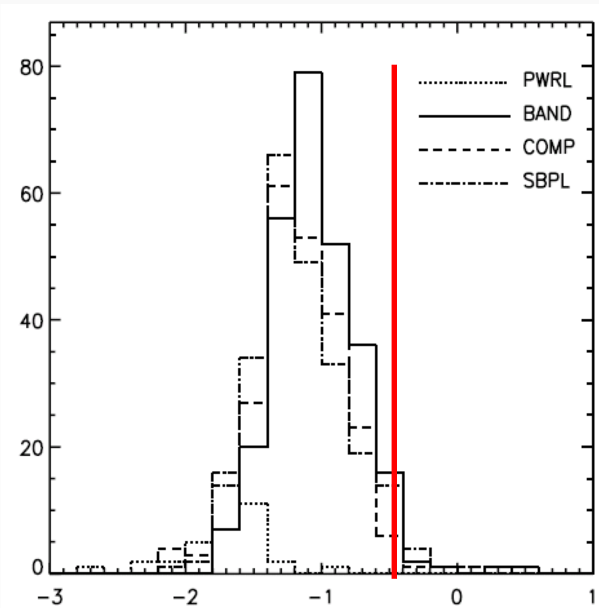
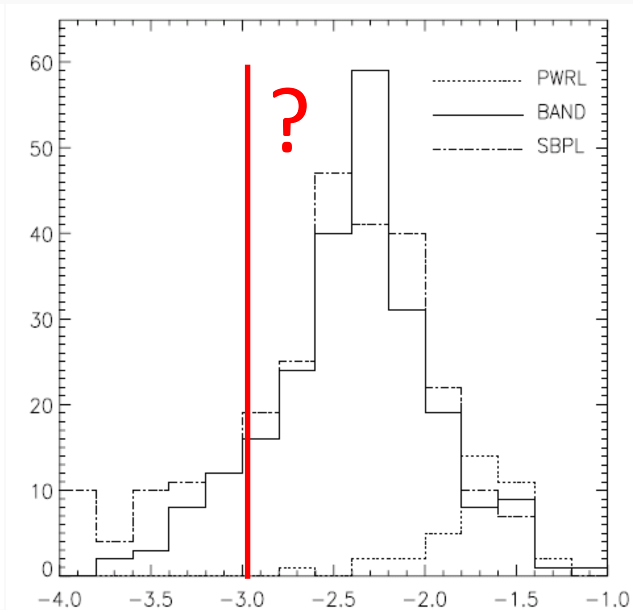


Comparison with the observations

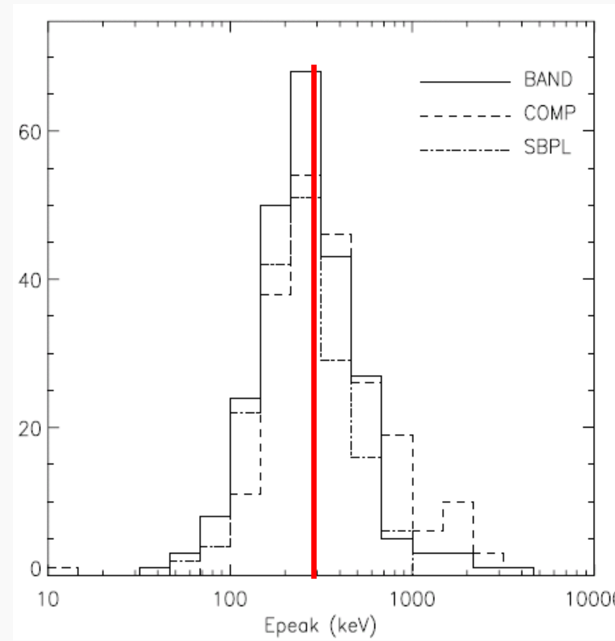
Kaneko et al 2006



low energy index (α)



high energy index (β)



peak energy (E_{peak})

Summary

Summary

- ✓ We calculate radiative transfer for the thermal radiation from GRB jet.
- ✓ The spectrum consists of higher energy jet component and lower energy cocoon component.
- ✓ The thermal radiation from GRB jet is NOT a blackbody but may be Band-like spectrum.